Sustained magmatic inflation and fault movement in the Asal-Ghoubbet Rift observed using 11 years of radar interferometry data

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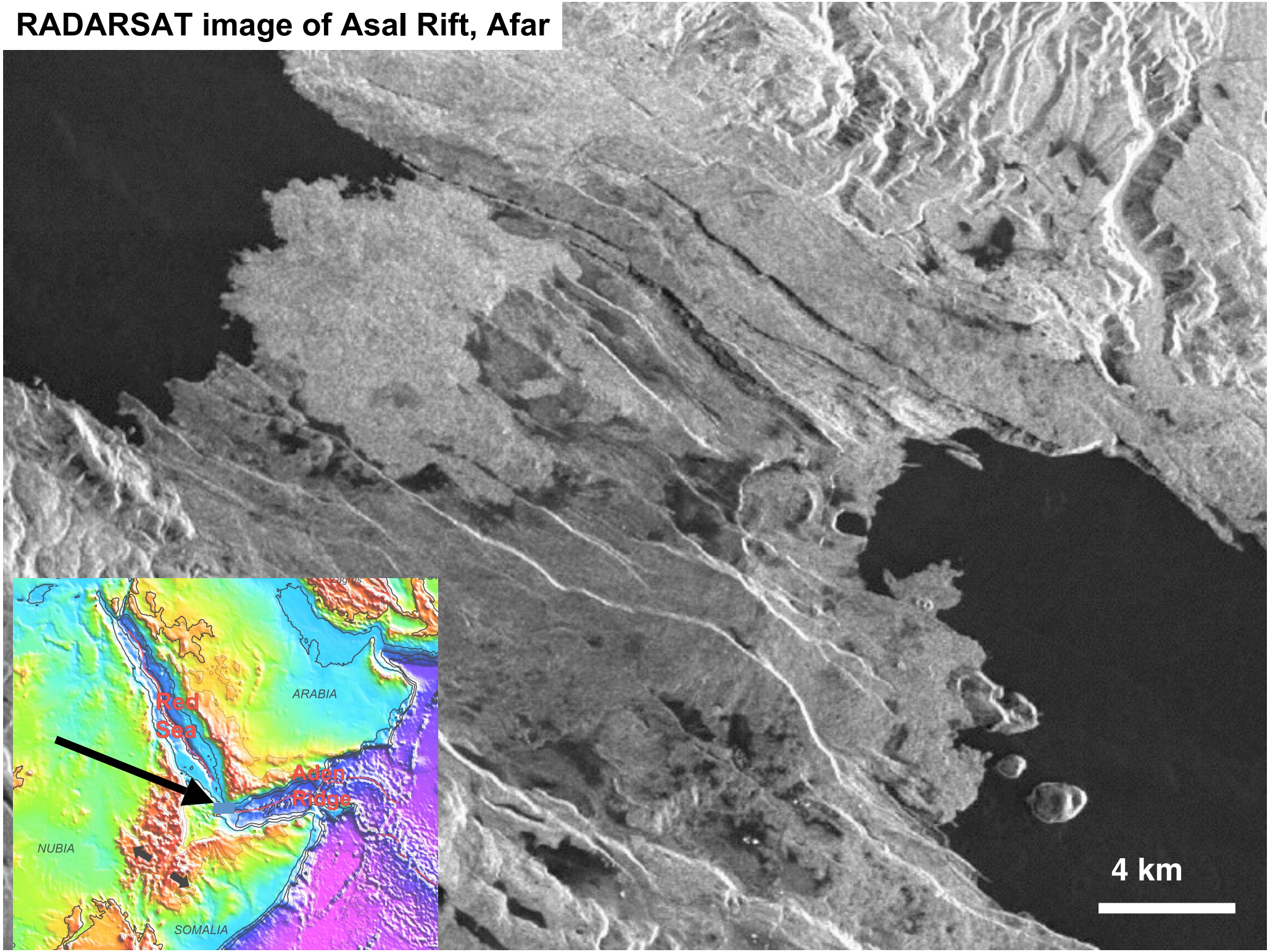
MRAV, Addis Ababa, Jan 2012

RADARSAT image of Asal Rift, Afar



1978 Rifting event

Seismicity:

6 Nov. 78 events (20 with M>3)

7 Nov.: 50-80 events/hr
(15 M>4, 108 M>3)
mb=5.2 at 17h30

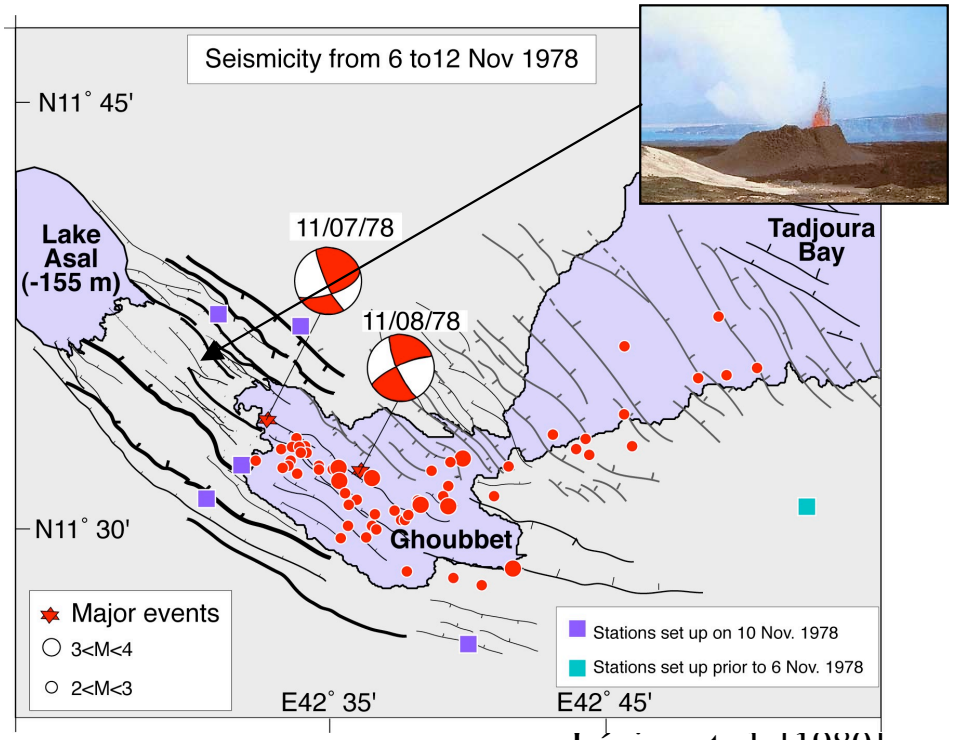
8 Nov.: mb=5.0 at 6h07

Nov-Dec.: Migration in N70˚E direction

Volcanic Activity:

Fissural eruption from 7-14 Nov.

16 10^6 m^3 of lava over 2 km^2



Lépine et al. [1980]

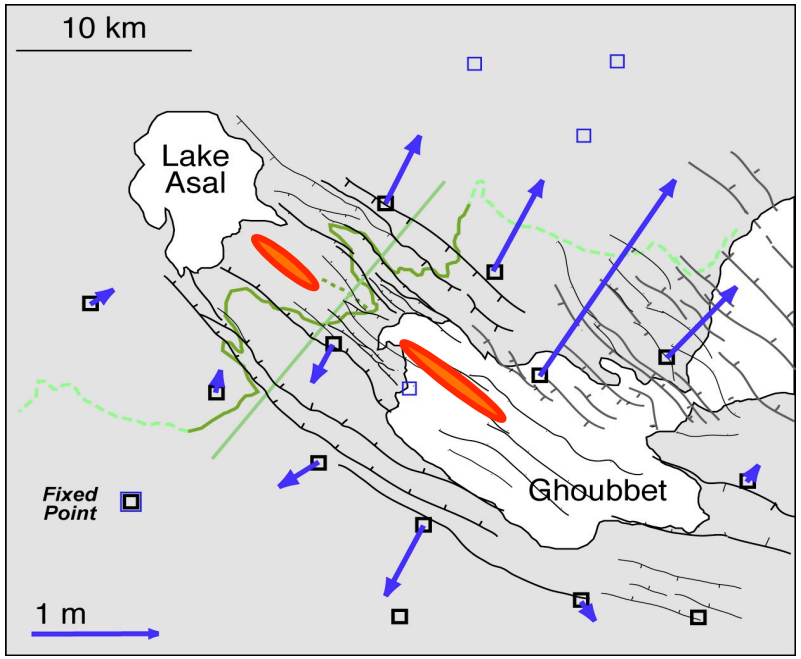
Focal Mechanisms, Dziewonski et al. [1987]

Geodetic deformation:

Trilateration network and leveling network set up in 1973 (IGN, IPGP, CERD) and resurveyed in 1978-1979

Horizontal displacement

- Extension across rift
  2-3 m of opening in Ghoubbet
- Contraction on margins
- Reactivation of normal faults and fissures

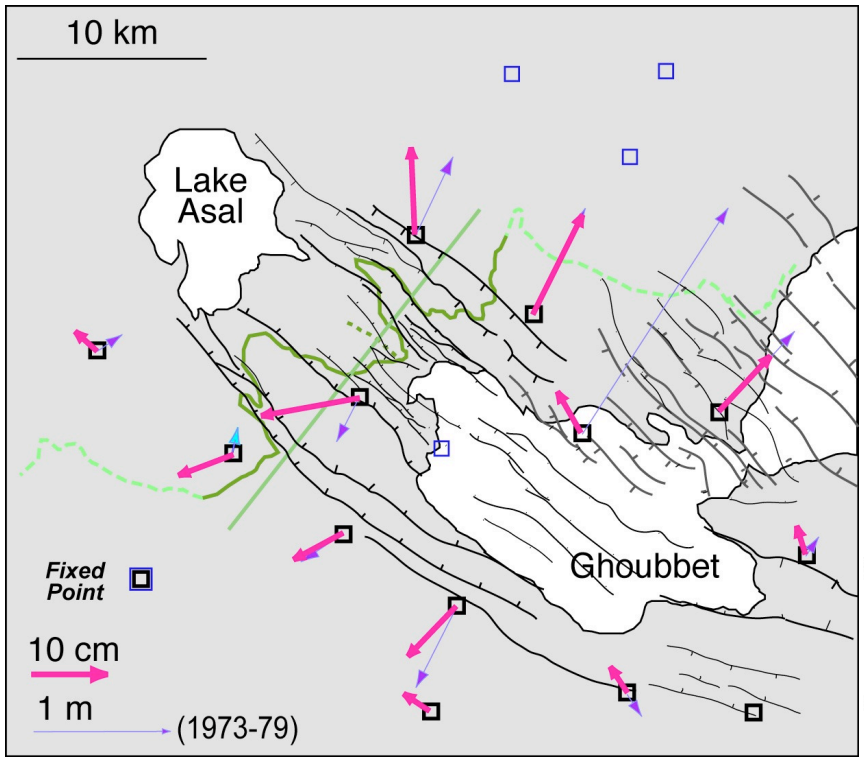


Figures: Ruegg et al. (1979)

Elastic Modeling: Tarantola et al. (1979, 1980)

Post-rifting period

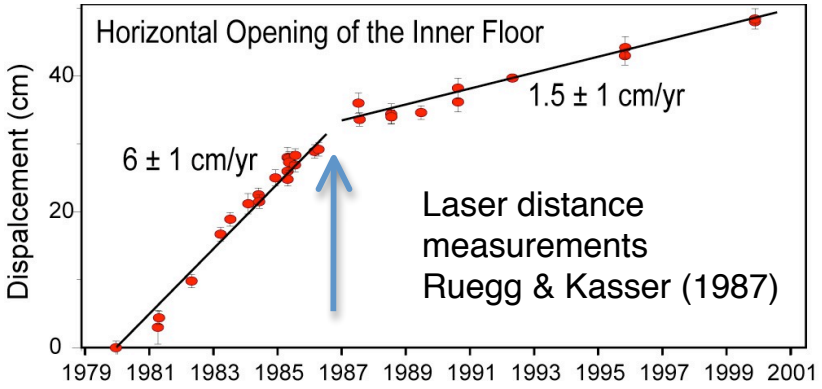
1979-1984 horizontal displacement

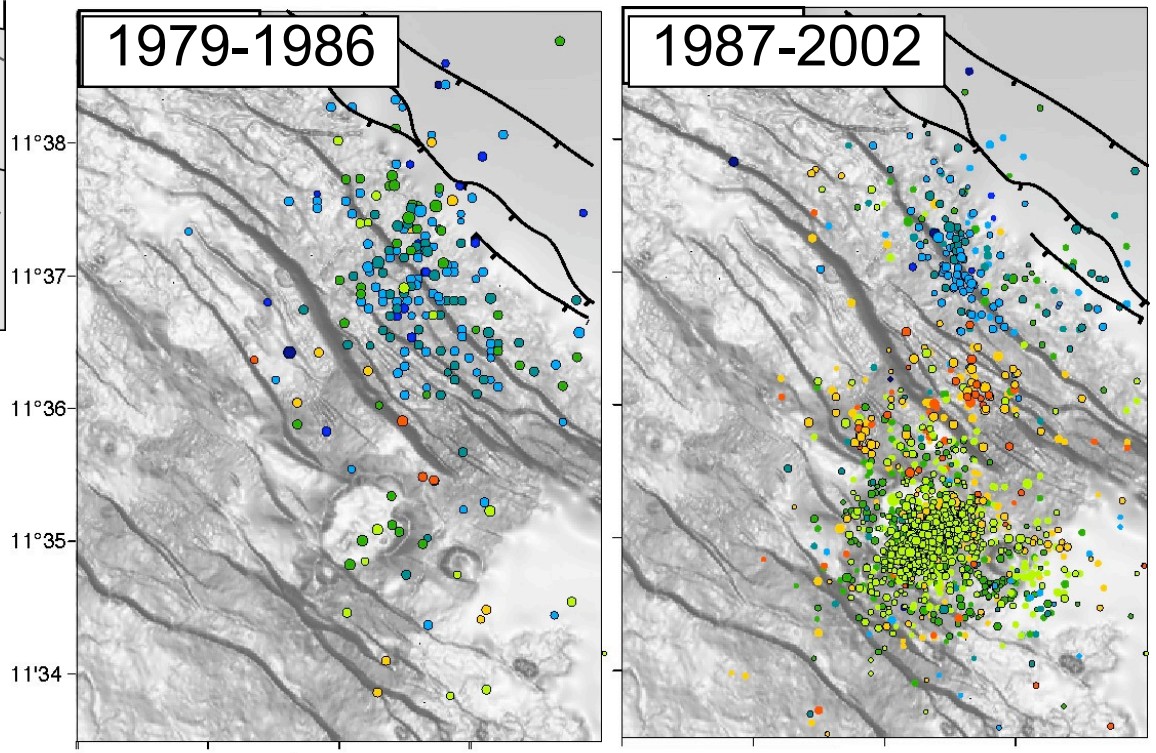


Re-surveyed in winter1983-1984

- Fast opening rate across rift
- Possible transition around 1986

22 years opening and micro-seismicity history

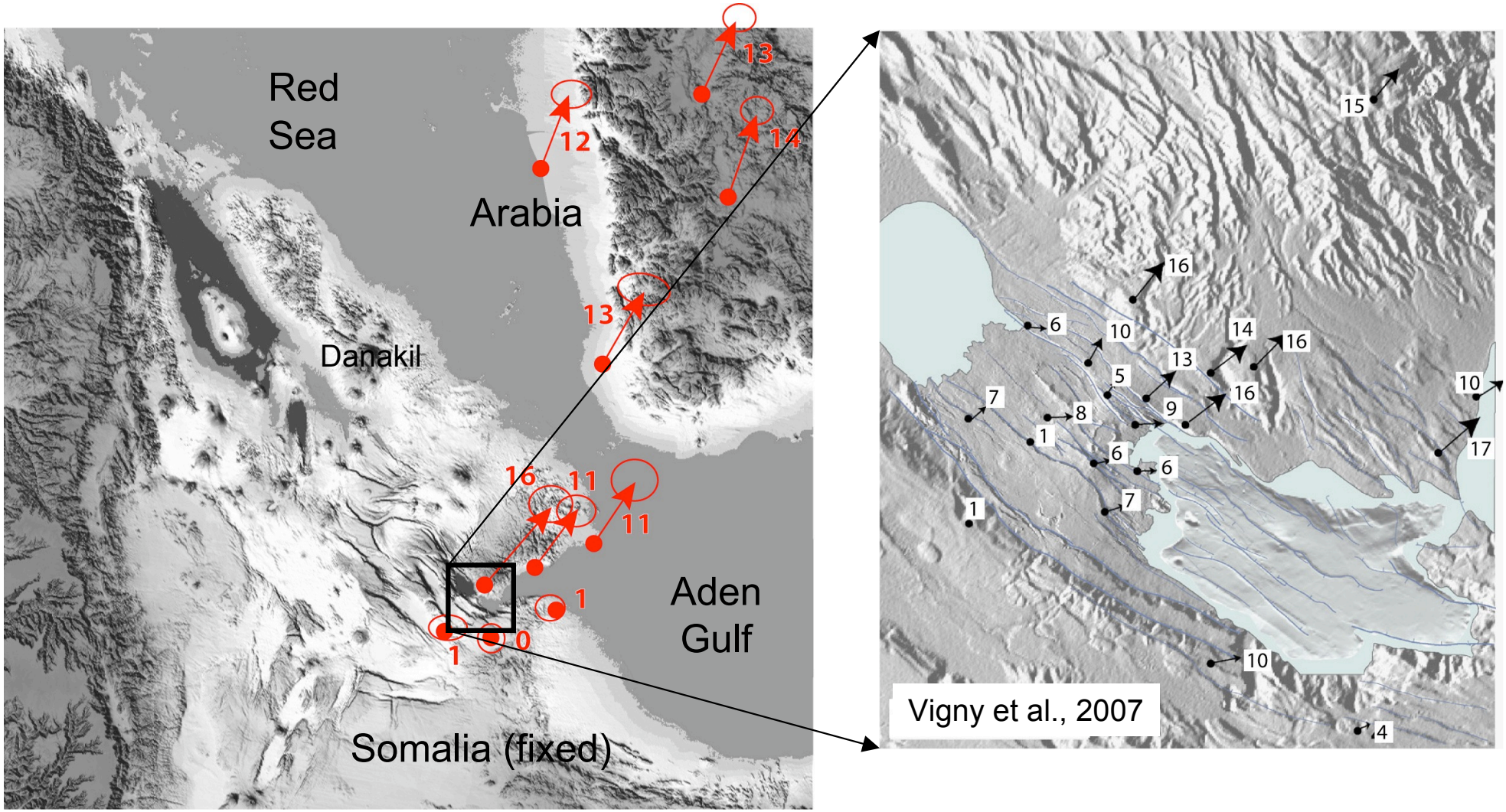




Doubre et al. (2007)

1991-2003 GPS velocities

(*Vigny et al., 2006, 2007*)



With respect to Somalia:

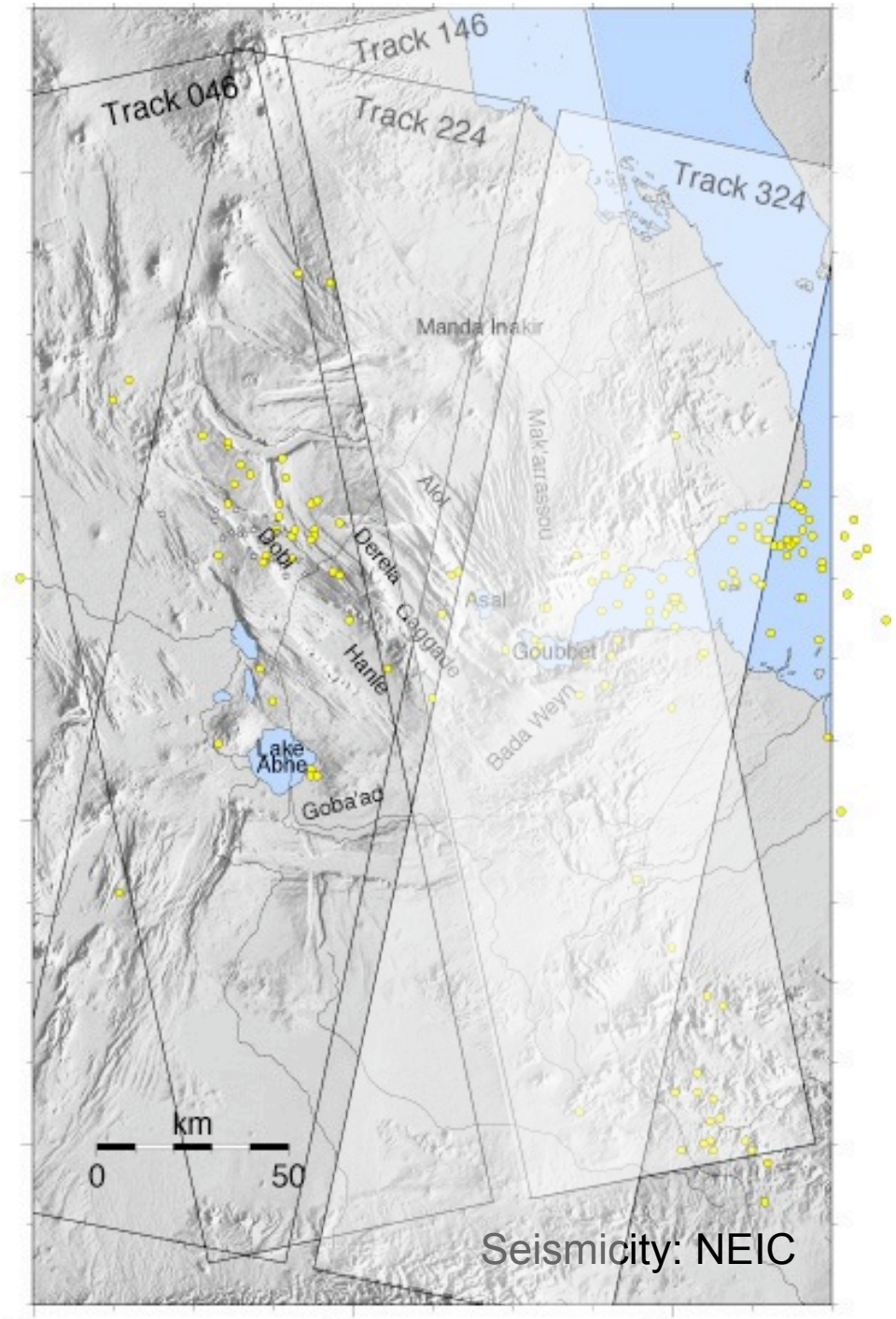
- ~N40˚E Motion of the Arabian plate and Danakil Block
- Opening between Asal Rift margins greater than far-field velocities

RADARSAT data

Acquisition time period 1997 – 2008:
- RADARSAT SAR data: 1997-2008
- Repeat period: 24 days
- More than 100 acquisitions on each track

InSAR:
- Excellent coherence over volcanic terrain
- Large errors due to phase propagation delay through troposphere

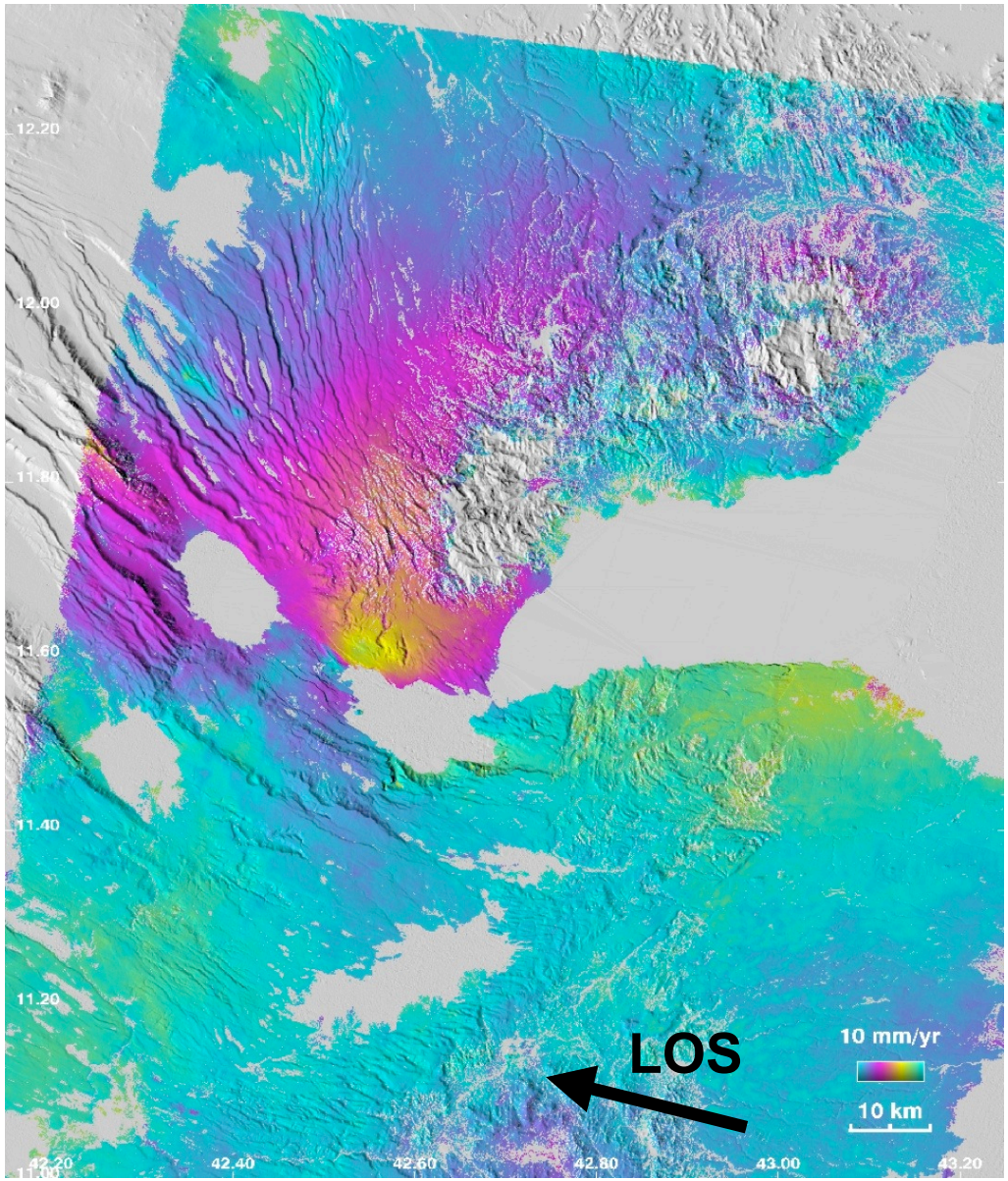
Analysis:
- Data stacking
- Time-series analysis using SBAS approach
- Ascending/descending passes combination

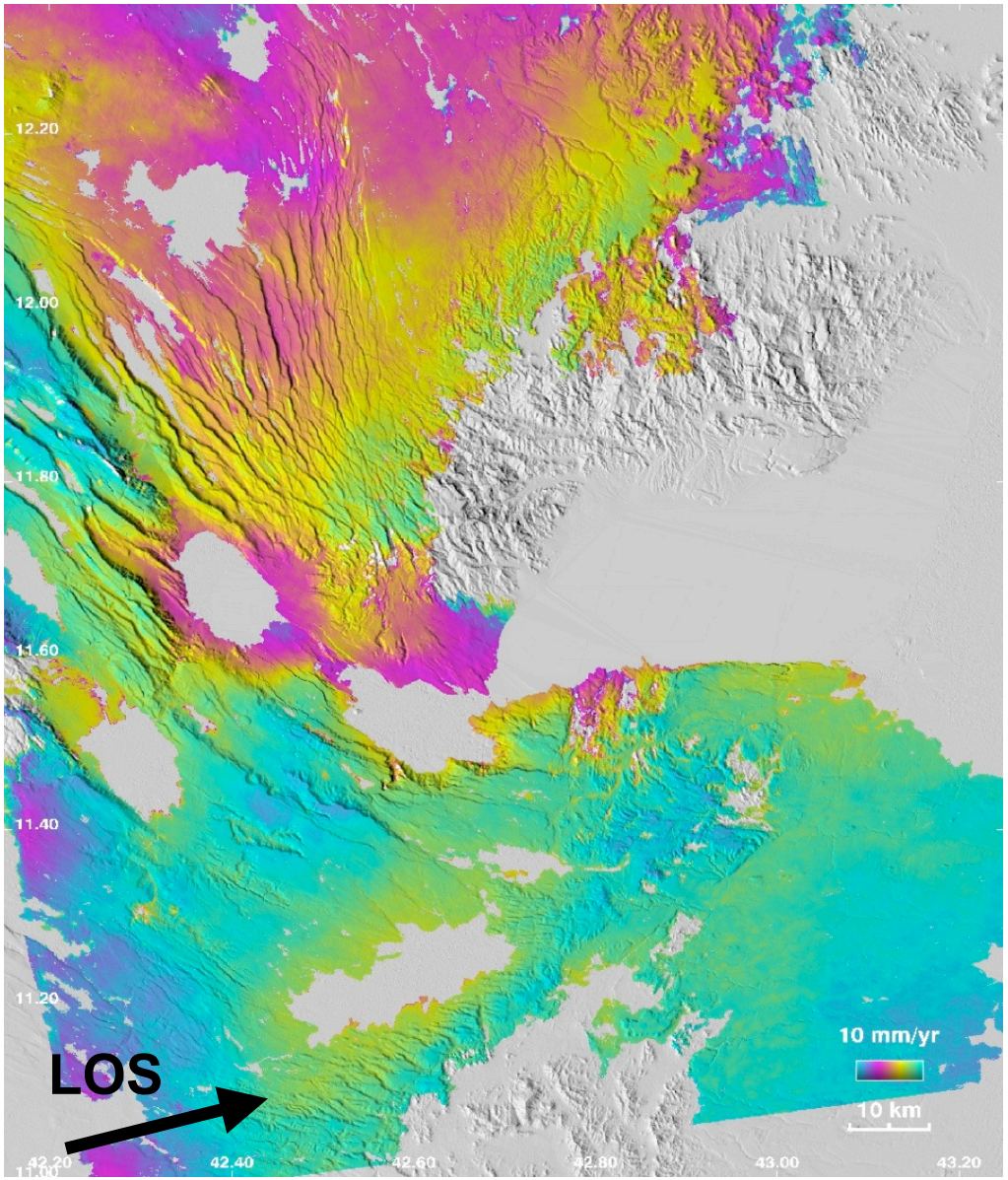


11-year average LOS velocity

Descending pass

Ascending pass



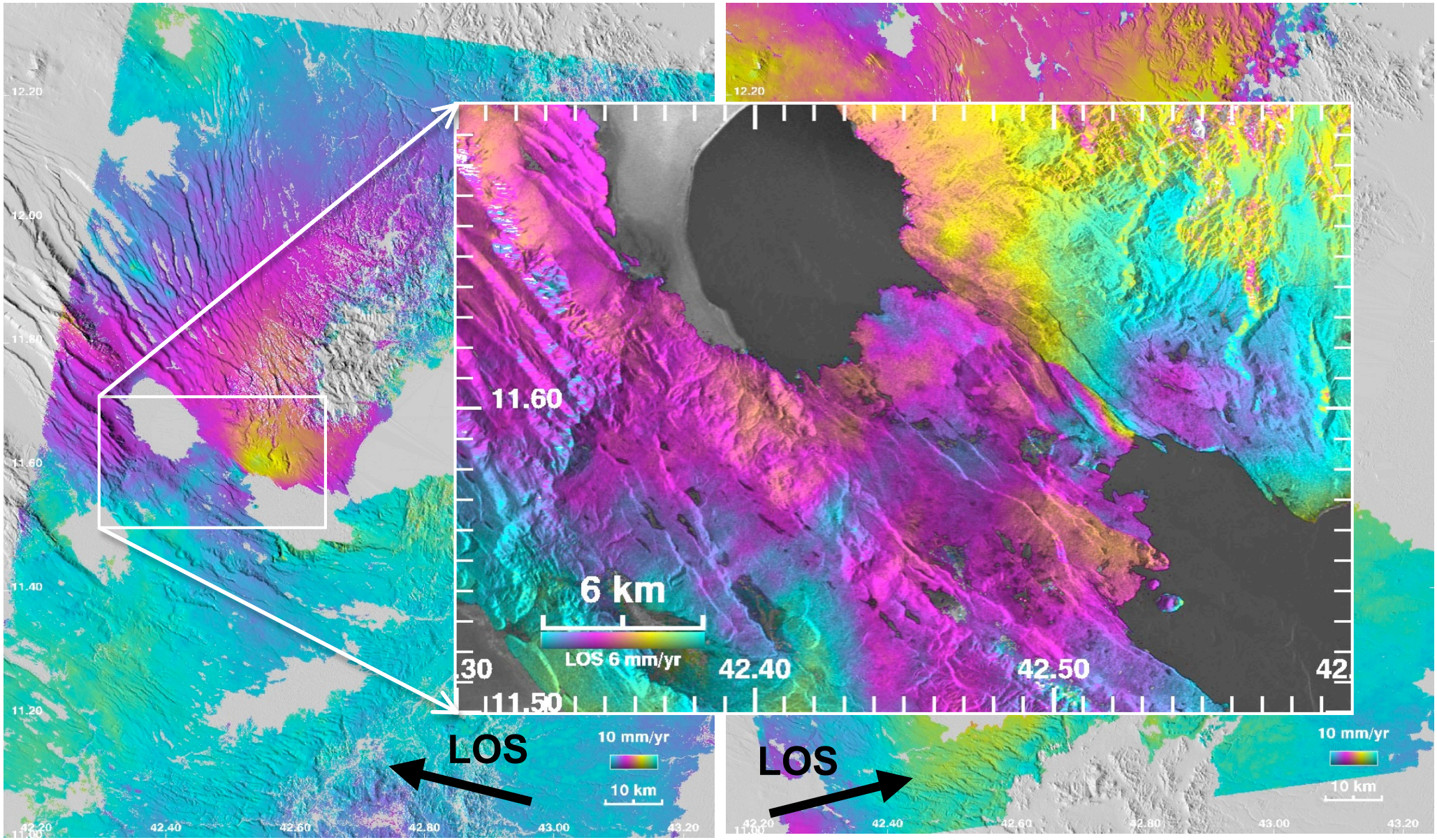


10 mm/yr

11-year average LOS velocity

Descending pass

Ascending pass

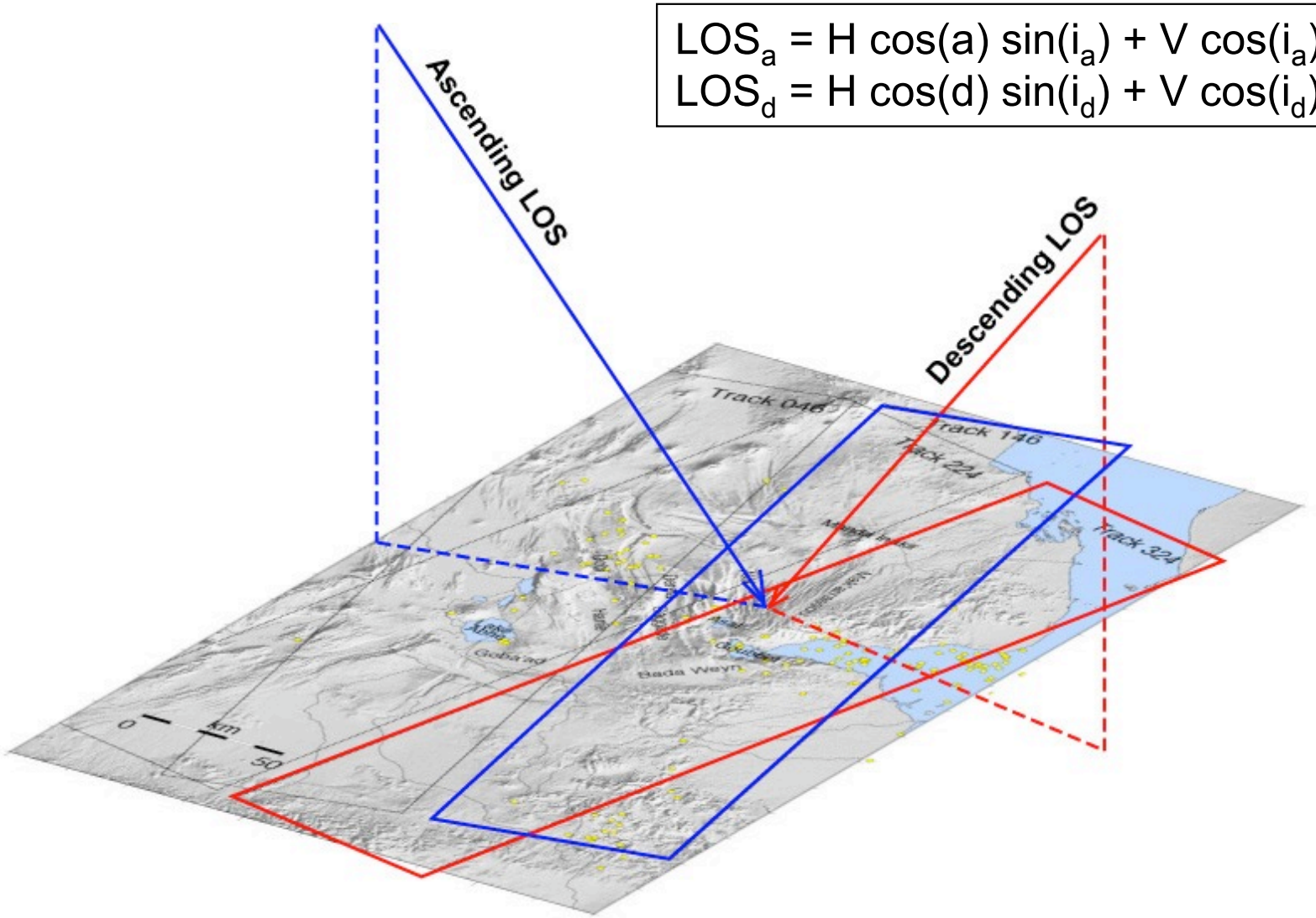


10 mm/yr

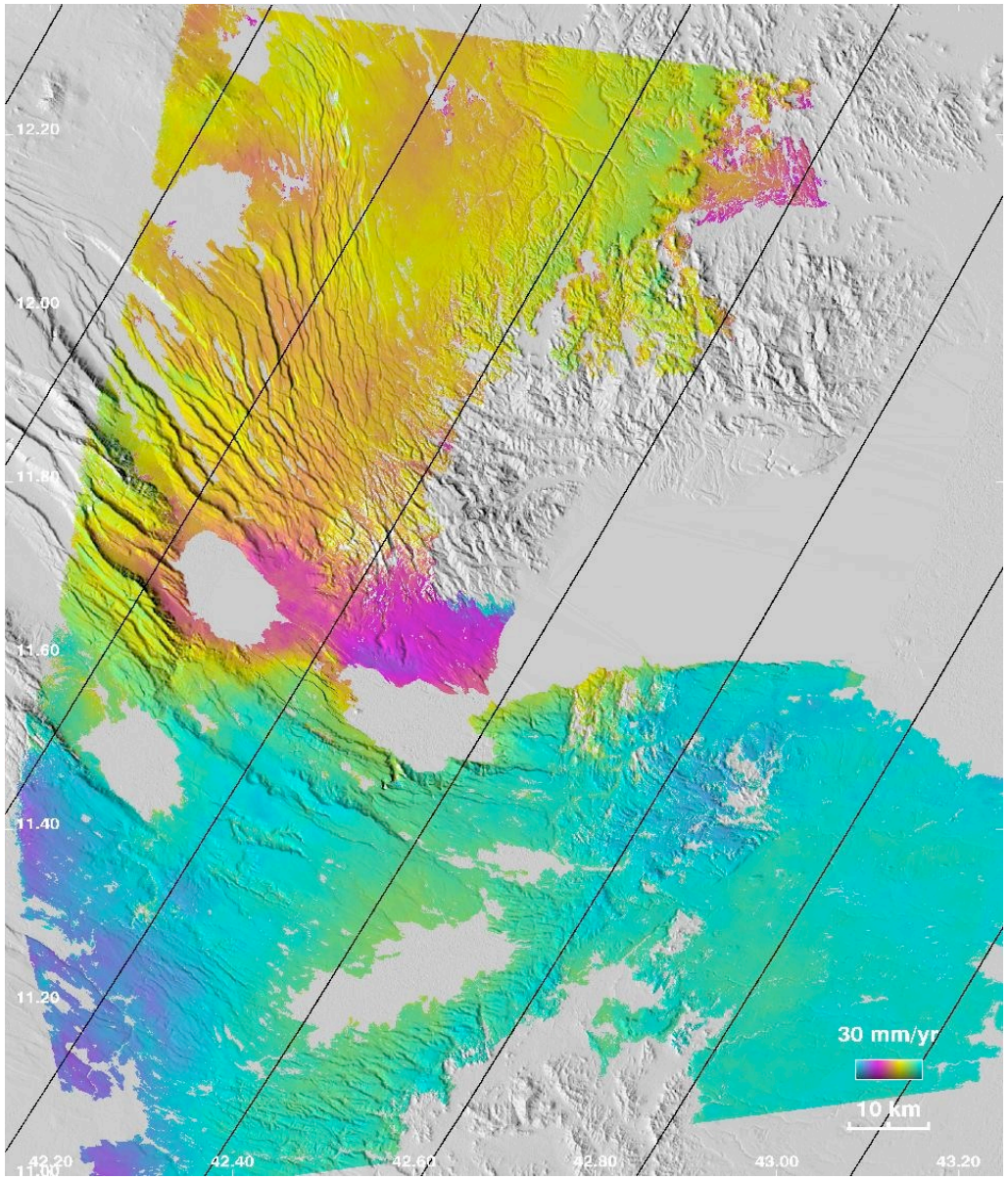
Horizontal and vertical components of velocity field:

- Assume horizontal field everywhere tangent to small circles about Arabia-Somalia rotation pole (N20.07˚,E25.49˚, Vigny et al., 2006)
- Solve for vertical and horizontal components of displacement

$$LOS_a = H \cos(a) \sin(i_a) + V \cos(i_a)$$
$$LOS_d = H \cos(d) \sin(i_d) + V \cos(i_d)$$

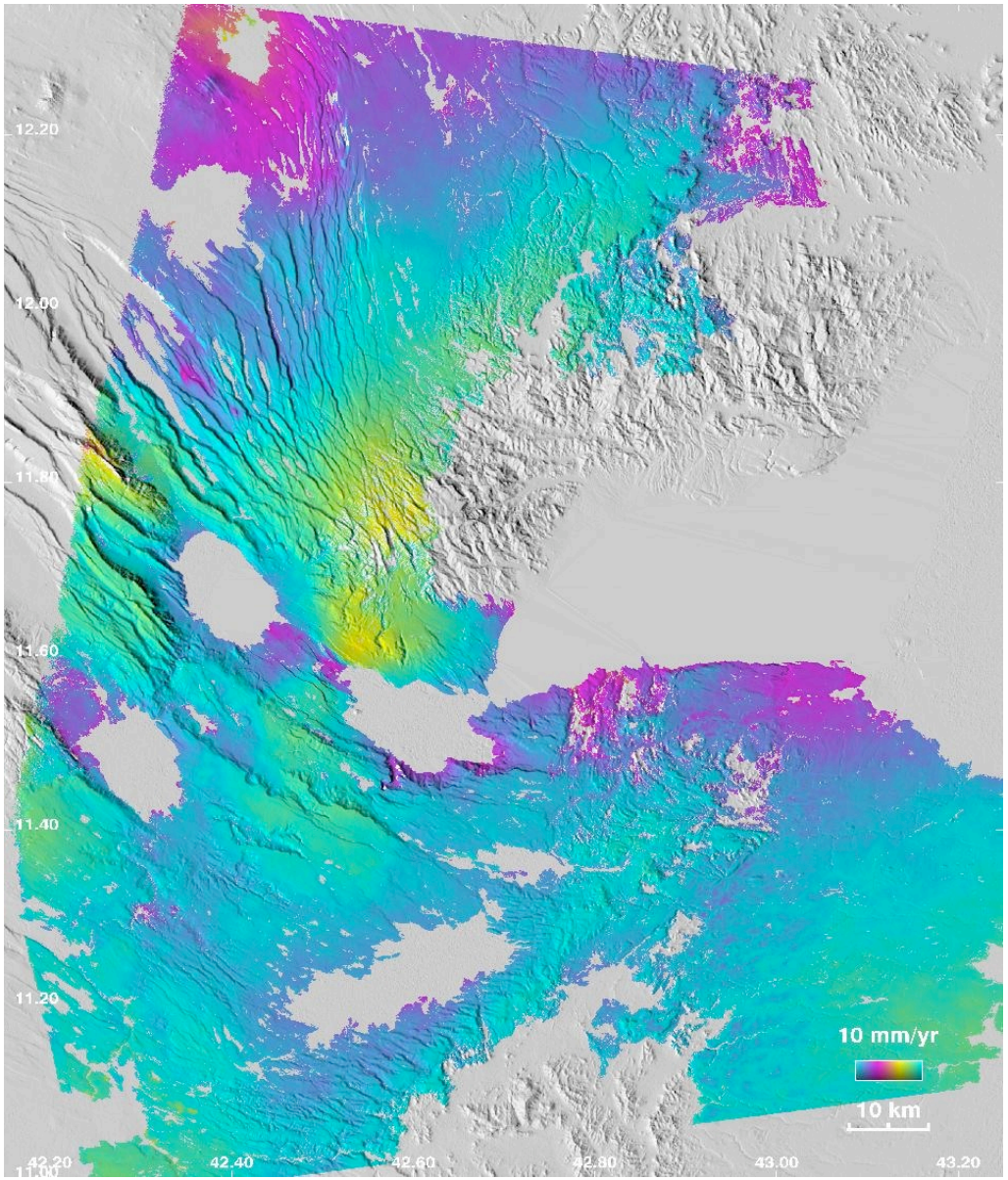


Horizontal velocity field



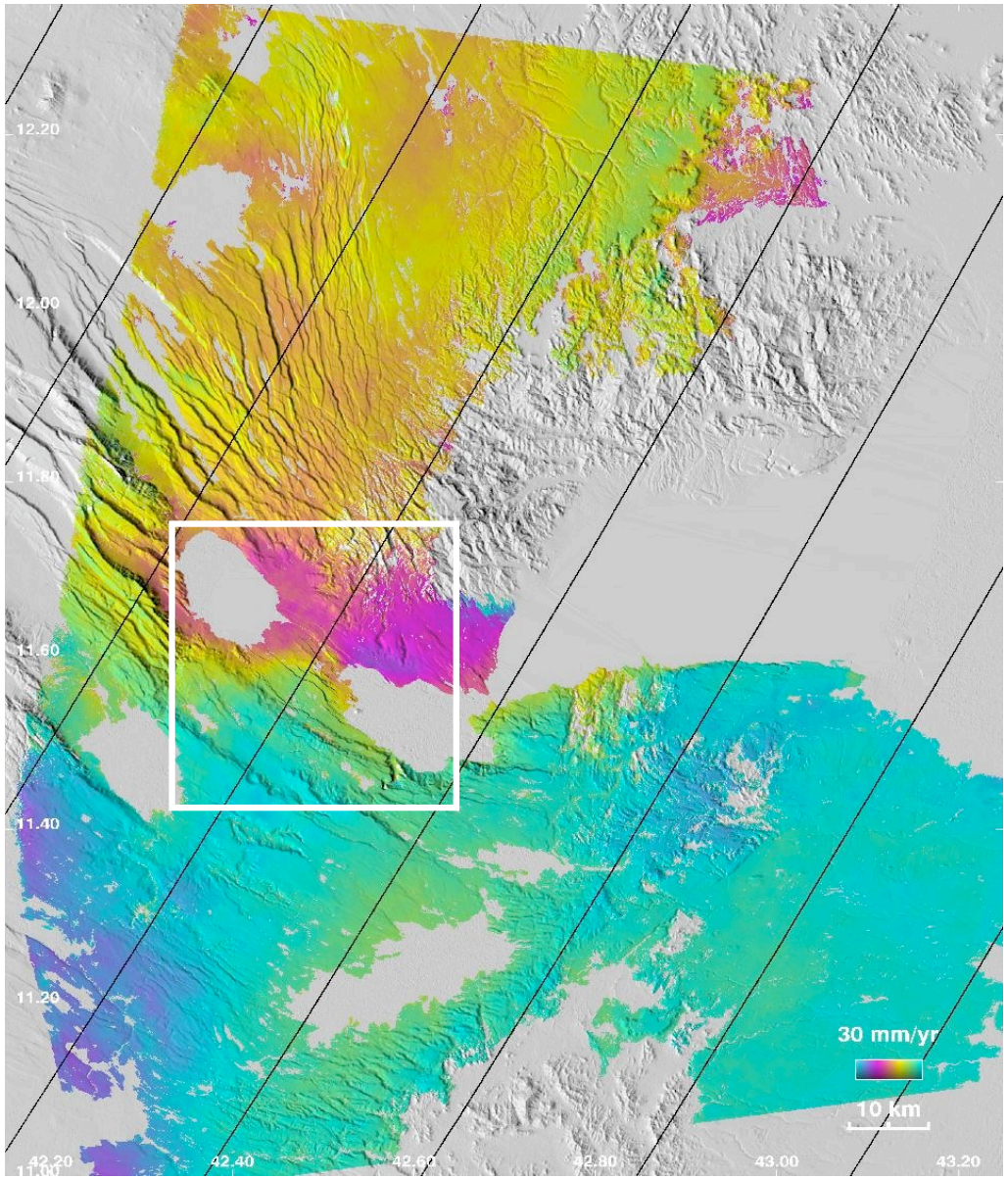
30 mm/yr

Vertical velocity field



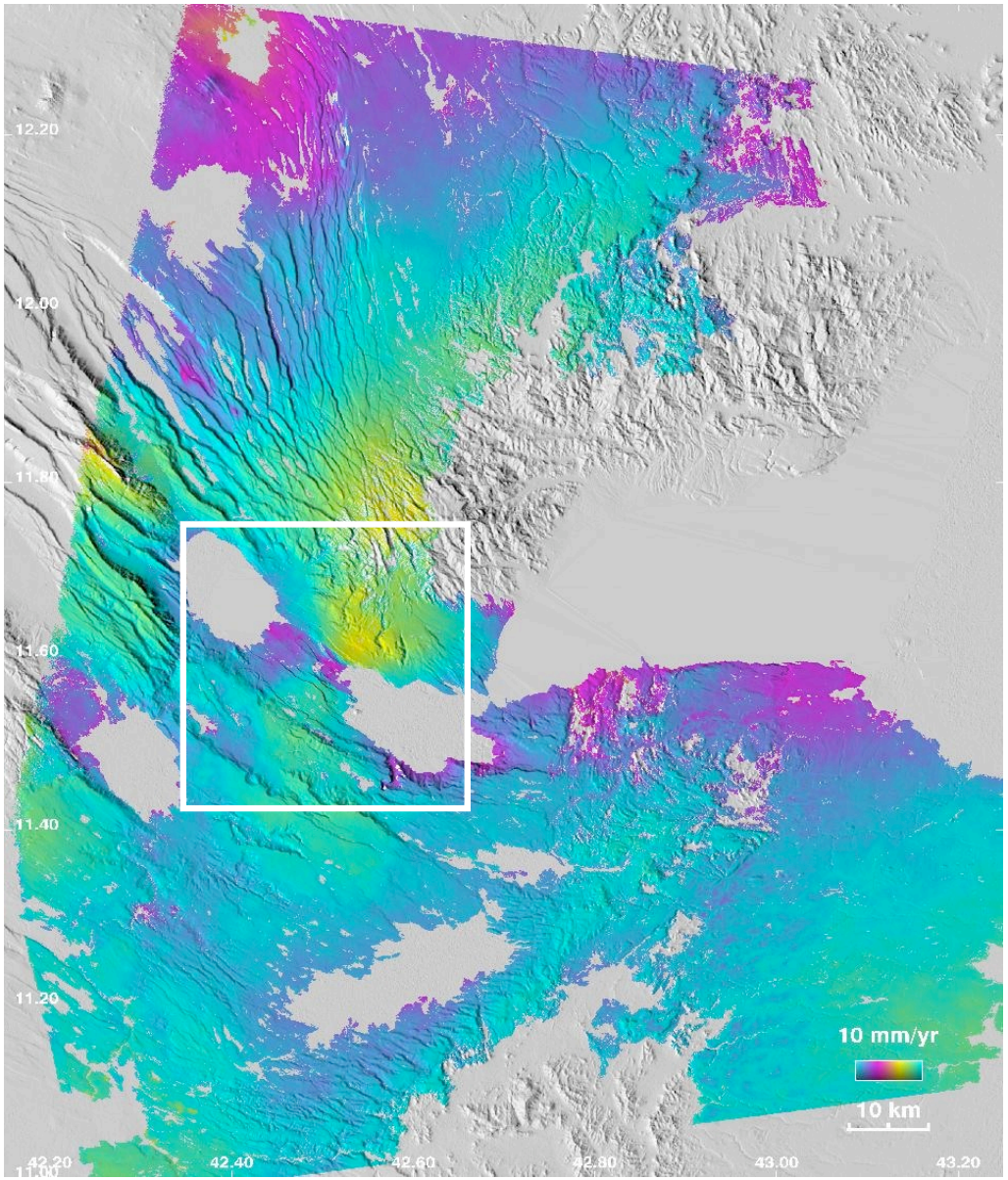
10 mm/yr

Horizontal velocity field



30 mm/yr

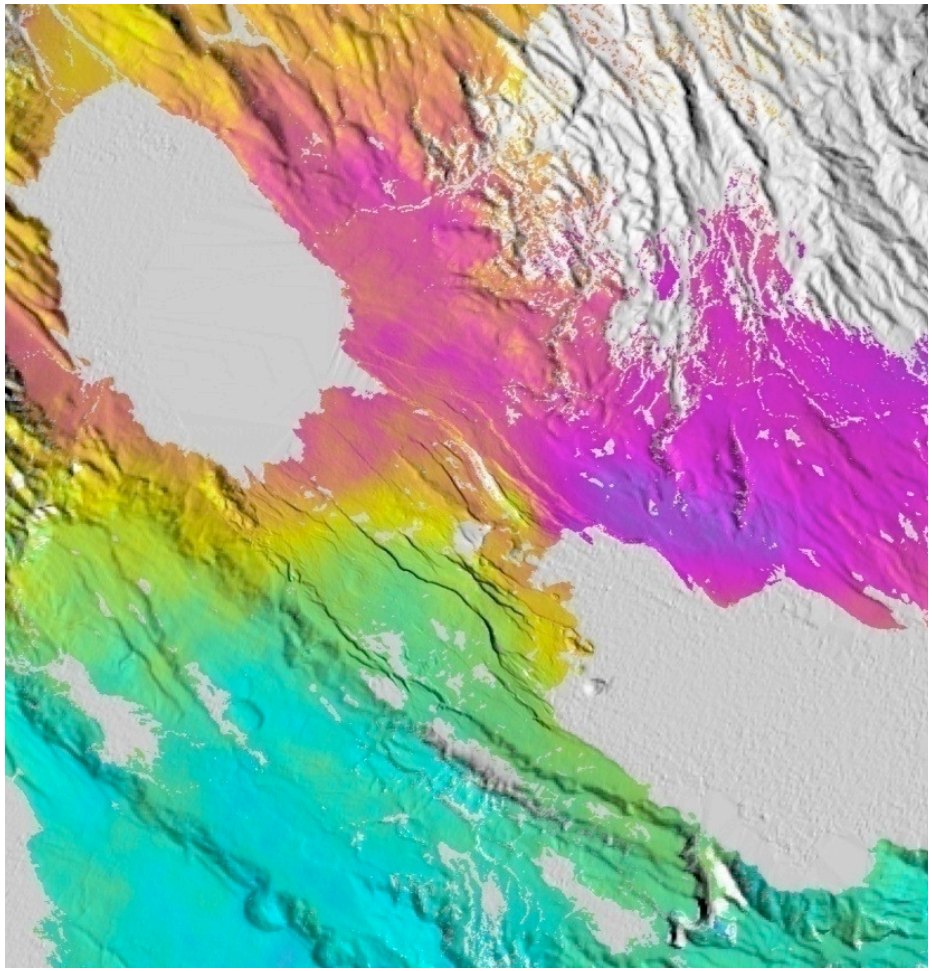
Vertical velocity field



10 mm/yr

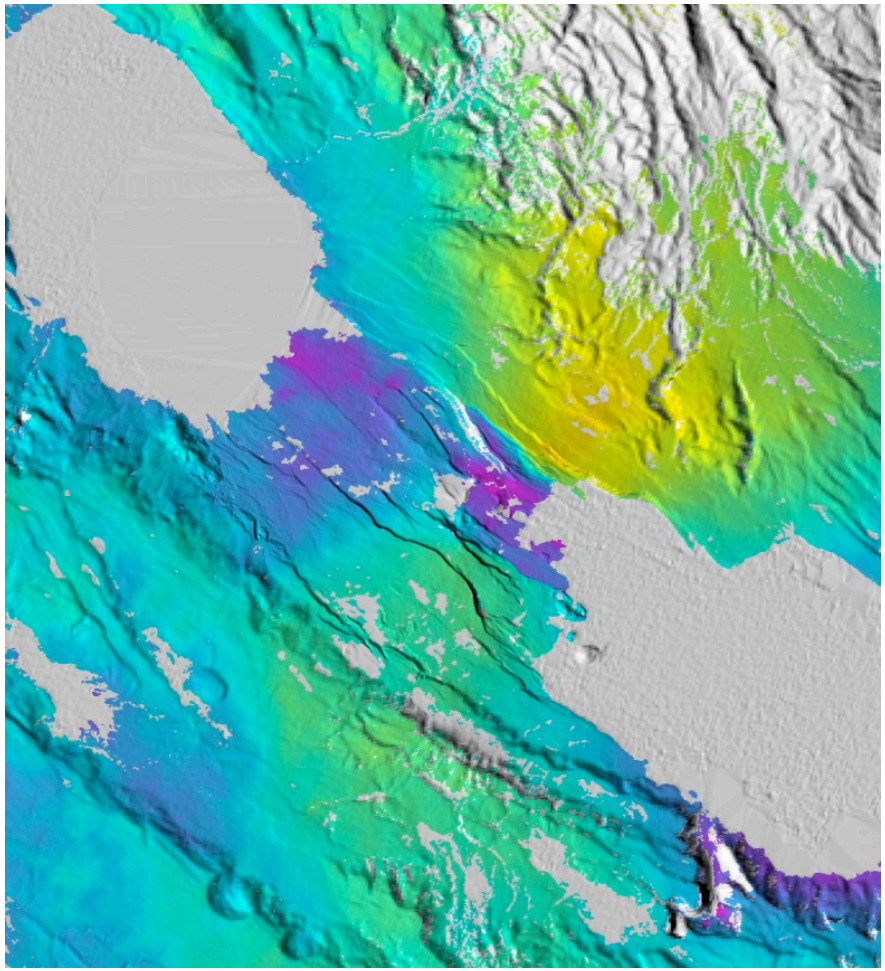
Asal-Ghoubbet Rift

Horizontal velocity field



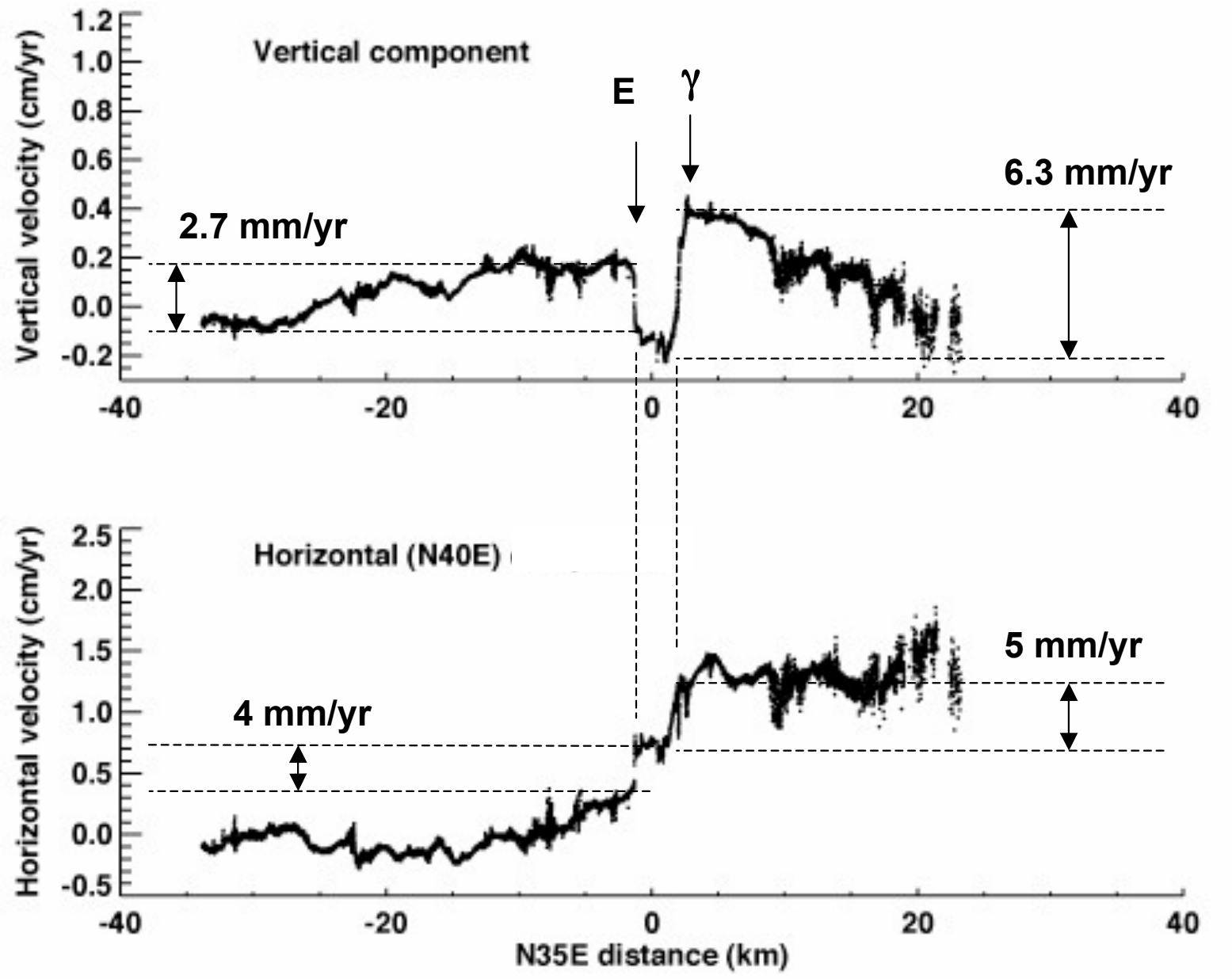
30 mm/yr

Vertical velocity field



10 mm/yr

Vertical and Horizontal velocity profiles



Fault E

Fault γ

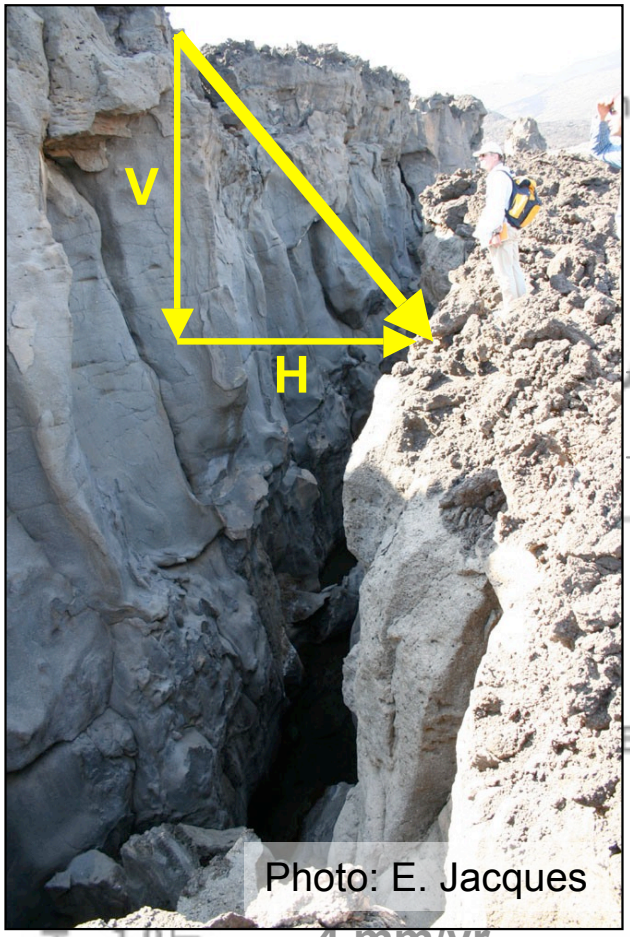
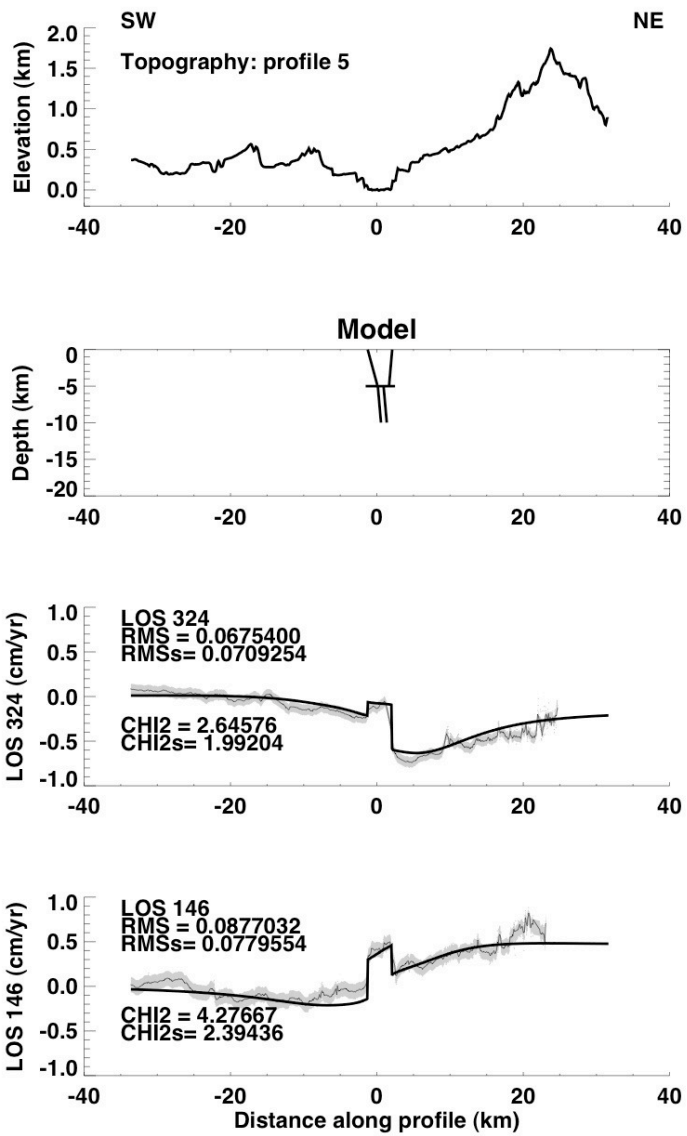


Photo: E. Jacques

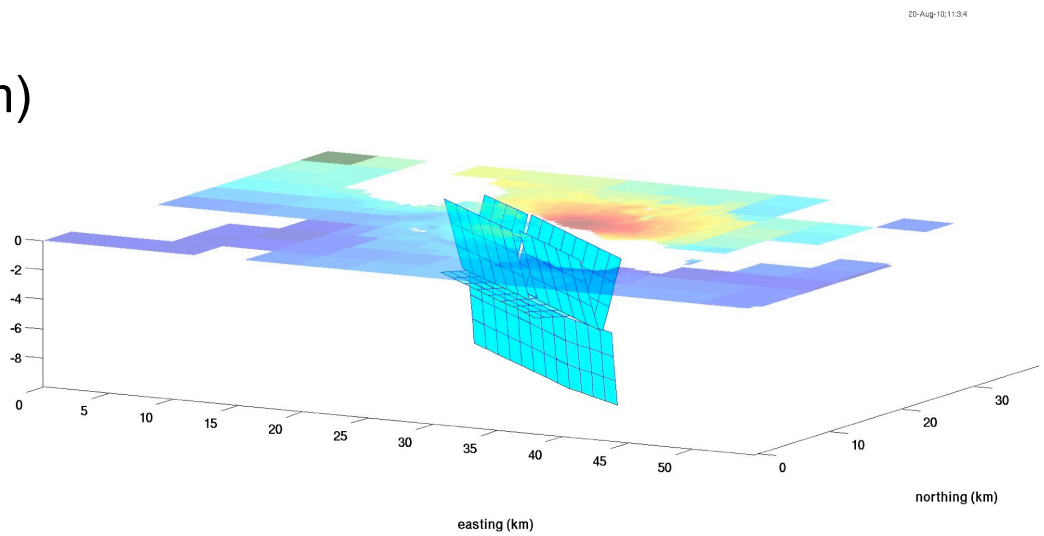
Photo: Y. Klinger

Forward model

Define geometry of structures:
Inflating body (5-20 km)
Faults opening and down-dip slip (0-5 km)



3-D inverse model



- Data: ascending (t146) and descending (t324) average velocity fields

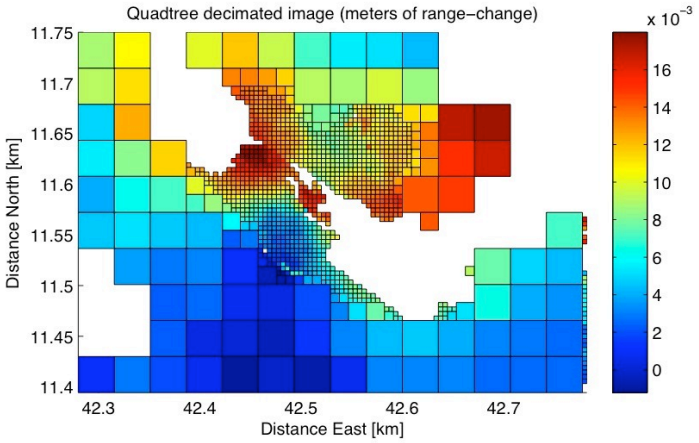
- Far-field plate motion is fixed based on GPS Arabia-Somalia rotation pole

-Solve displacement rate on shallow structures using non-negative, least squares inversion

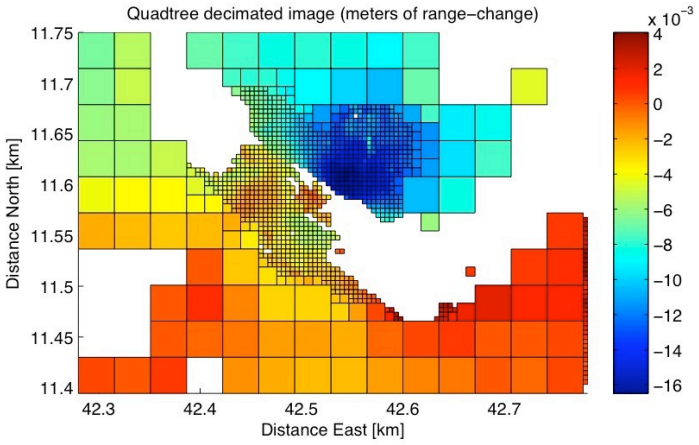
Data:
ascending/descending velocity

Quad-tree resampling based on distance to active structures

Ascending track

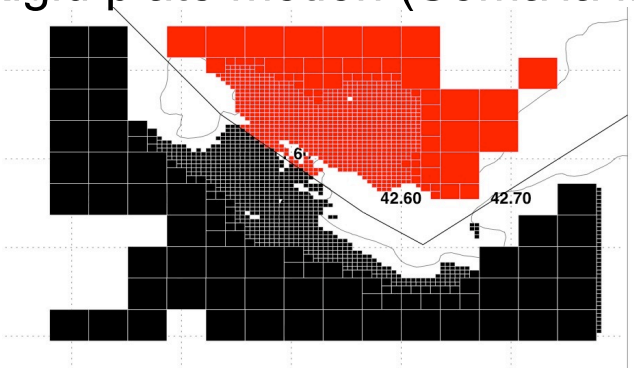


Descending track

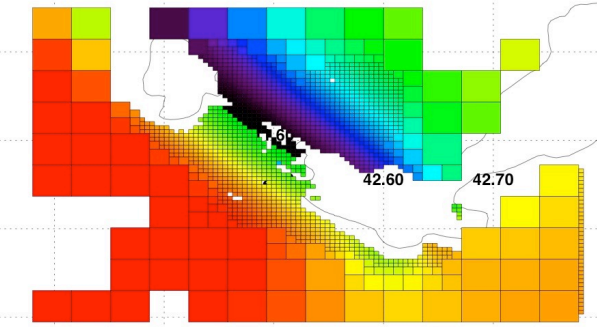


Far-field defined using GPS rotation pole

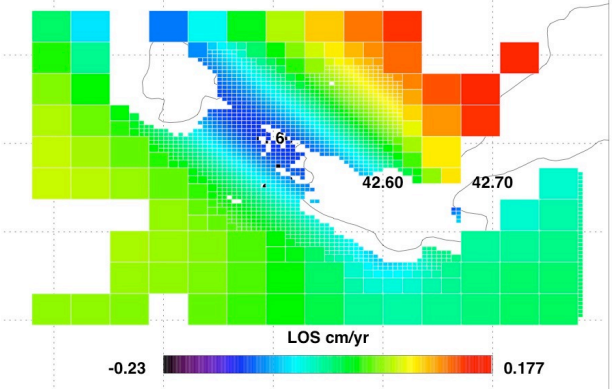
Rigid plate motion (Somalia fixed)



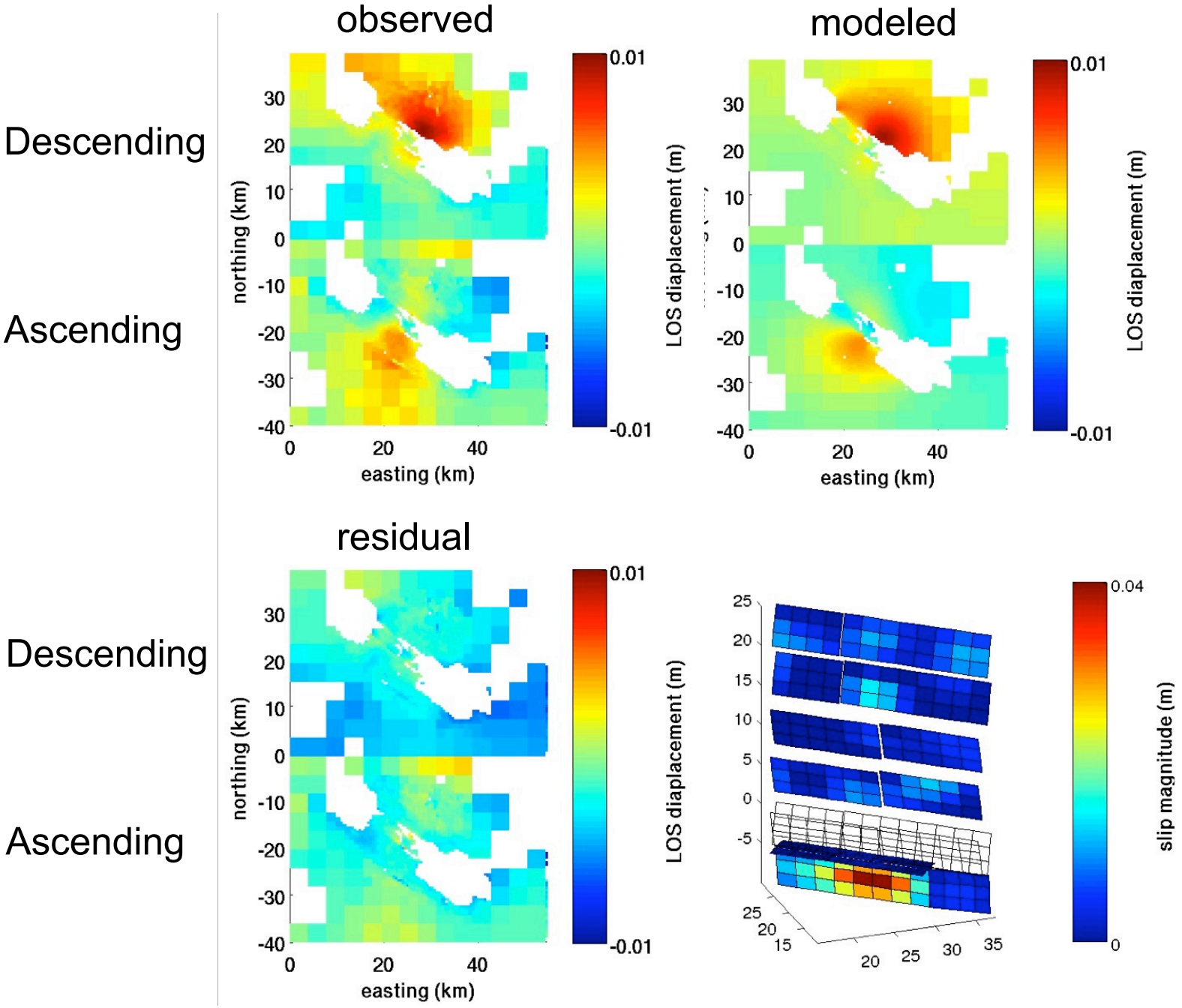
Back-slip movement on shallow part of boundary



Resulting plate movement



Inversion result: comparison between observed and modeled displacements

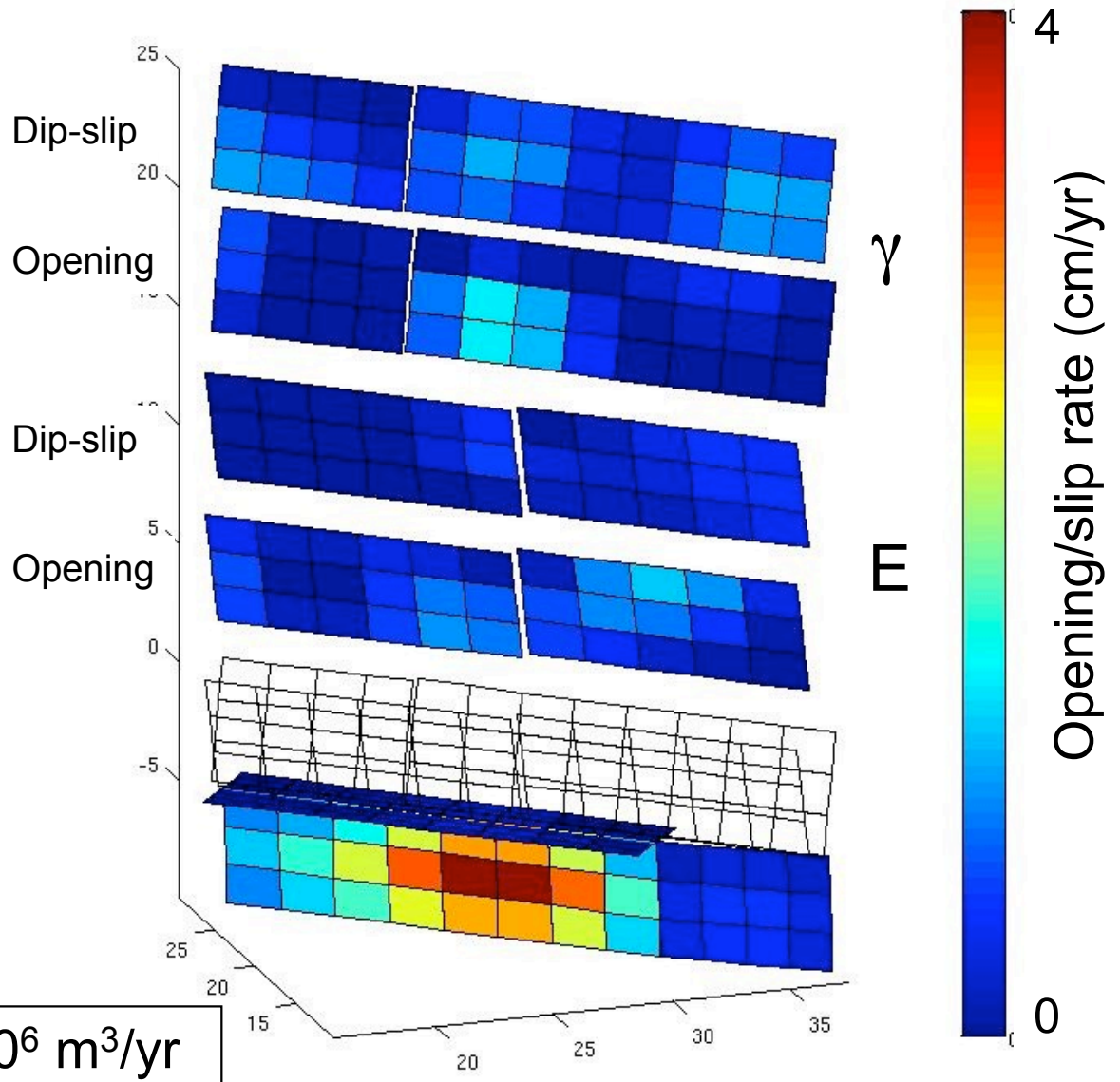


Inversion results: variable slip and opening solution

Inflating body
Dike: up to 4 cm/yr
Sill: 0.4 cm/yr
Moment rate: 2 10^6 m^3/yr

Fault opening and down-dip slip:
- Fault γ:
  Dip-slip: 1 - 1.1 cm/yr
  Opening: 0.6 - 1.4 cm/yr
  Moment rate: 0.4 10^6 m^3/yr
- Fault E:
  Dip-slip: 0.6 cm/yr
  Opening: 0.9 - 1.2 cm/yr
  Moment rate: 0.6 10^6 m^3/yr

Total inflation moment rate: 3 10^6 m^3/yr



Conclusion

- Diverging plate motion between Arabia and Somalia accommodated entirely across Asal Rift
- West of Asal Rift extension localized along Gaggade-Derella Rift
- Local opening rate across Asal exceeds current far-field plate motion
- Two main faults activated in 1978 seismo-magmatic event show continuous movement in dip-slip and opening directions

Rift model:

- Sustained inflation of magmatic body located between 5 and 10 km below Fieale caldera
- Faults γ and E kinematics involve down-dip and opening movements
- Maximum opening is localized at base of faults where they connect with inflating structure
- Total geometric moment rate on modeled structures is 3 10^6 m^3/yr
- For comparison, during the 1978 crisis:
    - Ardukoba eruption: 17 10^6 m^3
    - Dike opening (modeled by Tarantola et al., 1979): ~120 10^6 m^3
- Suggests that Asal-Goubbet Rift system may still be in transient mode as such a rate would mobilize the total 1978 volume in 40-50 years.